3

Radionavigation System Use

This section summarizes the plans of the Federal Government to provide general-purpose and special-purpose radio aids to navigation for use by the civil and military sectors. It focuses on three aspects of planning: (1) the efforts needed to maintain existing systems in a satisfactory operational configuration; (2) the development needed to improve existing system performance or to meet unsatisfied user requirements in the near term; and (3) the evaluation of existing and proposed radionavigation systems to meet future user requirements. Thus, the plan provides the framework for operation, development, and evolution of systems.

The Government operates radionavigation systems that meet most of the current and projected civil user requirements for safety of navigation, promotion of reasonable economic efficiency, and positioning and timing applications. These systems are adequate for the general navigation of military craft as well, but none completely satisfies all the needs of military missions or provides highly accurate, three-dimensional, worldwide navigation capability. GPS satisfies many of these general and special military requirements. GPS has broad potential for satisfying current civil user needs or for responding to new requirements that present systems do not satisfy. It could ultimately become the primary worldwide system for military and civil navigation and position location.

3.1 Existing Systems Used in the Phases of Navigation

It is generally accepted that the needs for navigation services derive from the activities in which the users are engaged, the locations in which these activities occur, the relation to other craft and physical hazards and, to some extent, the type of craft. Because these differences exist, navigation services are divided by classes or types of users and the phases of navigation. Detailed descriptions of the existing and proposed radionavigation systems are given in Appendix C. Estimates of the current numbers of users of Federally provided radionavigation systems are provided in Figure 3-1.

The following sections describe the approach employed to define the needs, requirements, and degree to which existing systems satisfy user needs.

3.1.1 Air Navigation

VOR/DME forms the basis of a safe, adequate, and trusted international air navigation system, and there is a large investment in ground equipment and avionics by both the Government and users. In view of this, it is intended to maintain the VOR/DME system at its present capability for a reasonable transition period for those systems being phased out after augmented GPS SPS is approved as a primary navigation system for domestic en route, terminal, nonprecision approach, and precision approach phases of flight.

As evidenced by user conferences and aircraft equipage, there is increasing interest and usage of GPS and Loran-C for air navigation. Both systems are certified as supplemental systems. In 1994, unaugmented GPS was also approved as a primary system for use in oceanic and remote airspace. Incremental improvements to WAAS will allow the termination of many existing ground-based radionavigation aids after an adequate transition period to allow users to equip with WAAS avionics.

Oceanic En Route: Oceanic en route air navigation is currently accomplished using inertial reference system/flight management computers, inertial navigation systems (INS), Loran-C, GPS, or a combination of these systems. Use of Doppler and celestial navigation are also approved. Use of VOR/DME, TACAN, and Loran-C is approved where there is adequate coverage.

Domestic En Route: Domestic en route air navigation services are presently being provided, except in some remote and offshore areas. The basic short-distance aid to navigation in the U.S. is VOR alone, or collocated with either DME or TACAN to form a VOR/DME or a VORTAC facility. This system is used for en route and terminal navigation for flights conducted under Instrument Flight Rules. It is also used by pilots operating under Visual Flight Rules. Loran-C and inertial systems are also used for domestic en route navigation. When inertial systems are used, their performance must be monitored through the use of an approved externally referenced radio aid to navigation. Loran-C and GPS both are approved as supplemental systems. GPS is also approved as a primary system for use in remote areas, and distance information based on GPS can be used to provide separation between aircraft in accordance with current DME standards.

Terminal: Terminal air navigation services are presently provided using VOR, VOR/DME, VORTAC, TACAN, NDB, GPS, or Loran-C. Loran-C and GPS are approved as supplemental systems.

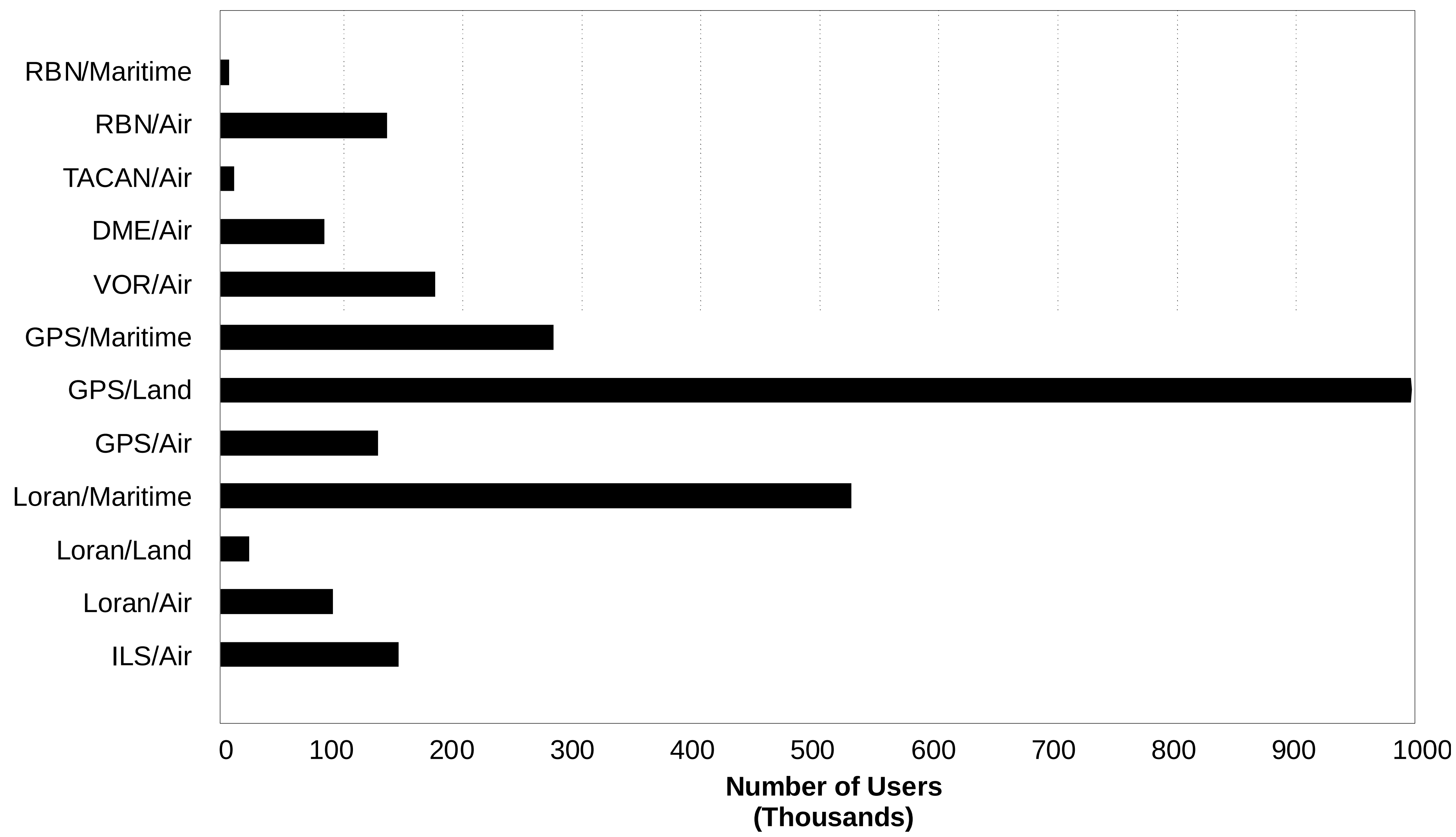


Figure 3-1. Estimated Current U.S. Radionavigation System User Population

Approach and Landing: Nonprecision approach navigation services are presently being provided using ILS localizer, VOR, VOR/DME, VORTAC, TACAN, GPS, or NDB. GPS is approved as a supplemental system. Presently, precision approach and landing requirements are met by ILS (Categories I, II, and III) and MLS (a limited number of Category I systems only).

3.1.2 Marine Navigation

Marine navigation comprises four major phases: inland waterway, harbor entrance and approach, coastal, and oceanic. The phase of navigation in which a mariner operates determines which radionavigation system or systems will be the most useful. While some radionavigation systems can be used in more than one phase of marine navigation, the most promising system to meet the most stringent requirements of the harbor entrance and approach and inland waterway phases of marine navigation is DGPS. With regard to the coastal phase of navigation, DGPS will provide the navigation features currently being met by Loran-C as it is used in the repeatable mode of navigation.

Inland Waterway Phase: This phase of navigation is concerned primarily with those vessels that are not oceangoing. Specific quantitative requirements for navigation on rivers and other inland waterways have been developed. Visual and audio aids to navigation, radar, and intership communications are presently used to enable safe navigation in those areas. However, DGPS is expected to play an increasing role in this phase of navigation.

Harbor Entrance and Approach Phase: Navigation in the harbor entrance and approach areas is accomplished through use of fixed and floating visual aids to navigation, radar, and audible warning signals. The growing desire to reduce the incidence of accidents and to expedite movement of traffic during periods of restricted visibility and ice cover has resulted in the implementation of VTS along with AIS in certain port areas and investigation of the use of radio aids to navigation. DGPS coverage includes all coasts of the continental U.S. and parts of Alaska, Hawaii, and the Great Lakes. The system provides better than 10 meter accuracy.

Coastal Phase: Navigation service for operation within the coastal area is provided by Loran-C, GPS and DGPS. Radio Direction Finders (RDF), required in some merchant ships by international agreement for search and rescue purposes, are also used with the radiobeacon system for navigation.

Ocean Phase: Navigation on the high seas is accomplished by the use of dead-reckoning, celestial fixes, self-contained navigation systems (e.g., inertial systems), Loran-C and GPS. GPS is now the system of choice. Worldwide coverage by most ground-based systems such as Loran-C is not practicable.

3.1.3 Space Applications

There are numerous uses of GPS for space navigation; many are discussed in Section 2. Several spacecraft including the ISS, the Space Shuttle, and numerous small satellites are using or will be using GPS for navigation. Some of these spacecraft will use GPS for support of instrument pointing, scientific data processing and, in the case of Space Shuttle and Reusable Launch Vehicles, for re-entry and landing as well as during orbital operations. The private sector is also implementing the use of GPS in space applications such as low Earth orbiting communication satellites and Earth sensing satellites.

3.1.4 Land Navigation

GPS, in conjunction with other systems, is used in land vehicle navigation. Government and industry have sponsored a number of projects to evaluate the feasibility of using existing and proposed radionavigation systems for land navigation. Operational tests have been completed that use in-vehicle navigation systems and electronic mapping systems to provide real-time route guidance information to drivers. GPS is used for automatic vehicle location for bus scheduling and fleet management. Operational tests are either planned or in progress to use radionavigation for route guidance, in-vehicle navigation, providing real-time traffic information to traffic information centers, and improving emergency response. Several transit operational tests will use automatic vehicle location for automated dispatch, vehicle re-routing, schedule adherence, and traffic signal pre-emption. Railroads have tested and continue to test GPS and DGPS as a part of positive train control systems for freight as well as high-speed passenger train operations. GPS and dead-reckoning/map-matching are being developed as systems that take advantage of radionavigation systems and at the same time improve safety and efficiency of land navigation.

3.1.5 Uses Other Than Navigation

These uses are concerned primarily with the application of GPS for geodesy and surveying, positioning in support of mapping, charting, and geographical information systems, monitoring of Earth motions, meteorological parameter determination position, and time and frequency determination. Users with these applications represent a large percentage of the GPS user community and involve all levels of government, academia, and industry. Many of the products supported by these applications are those traditionally provided by the Federal government. These include the National Spatial Reference System, nautical and aeronautical charts, weather prediction, earthquake studies, and inland waterways management. In the Inland Waterways, Harbor Entrance and Approach and Coastal Phases, DGPS is being used extensively by the USCG to position floating aids as well as fixed aids to navigation. Additionally, the USACE is using DGPS to conduct surveying, aid positioning, dredging operations, and revetment maintenance.

Many applications of GPS and augmented GPS are anticipated for Federal, state, and local governments, industry, and consumers. The Government does not have a responsibility under law to provide radionavigation systems for these users. However, these applications represent a large (and growing) percentage of the civil radionavigation user community and are recognized in the radionavigation planning process.

3.2 Existing and Developing Systems - Status and Plans

Figure 3-2 shows the operating plans for Federally provided common-use radionavigation systems.

3.2.1 Global Positioning System (GPS)

GPS is a space-based positioning and navigation system designed to provide worldwide, all weather, passive, three-dimensional position, velocity, and time data.

A. User Community

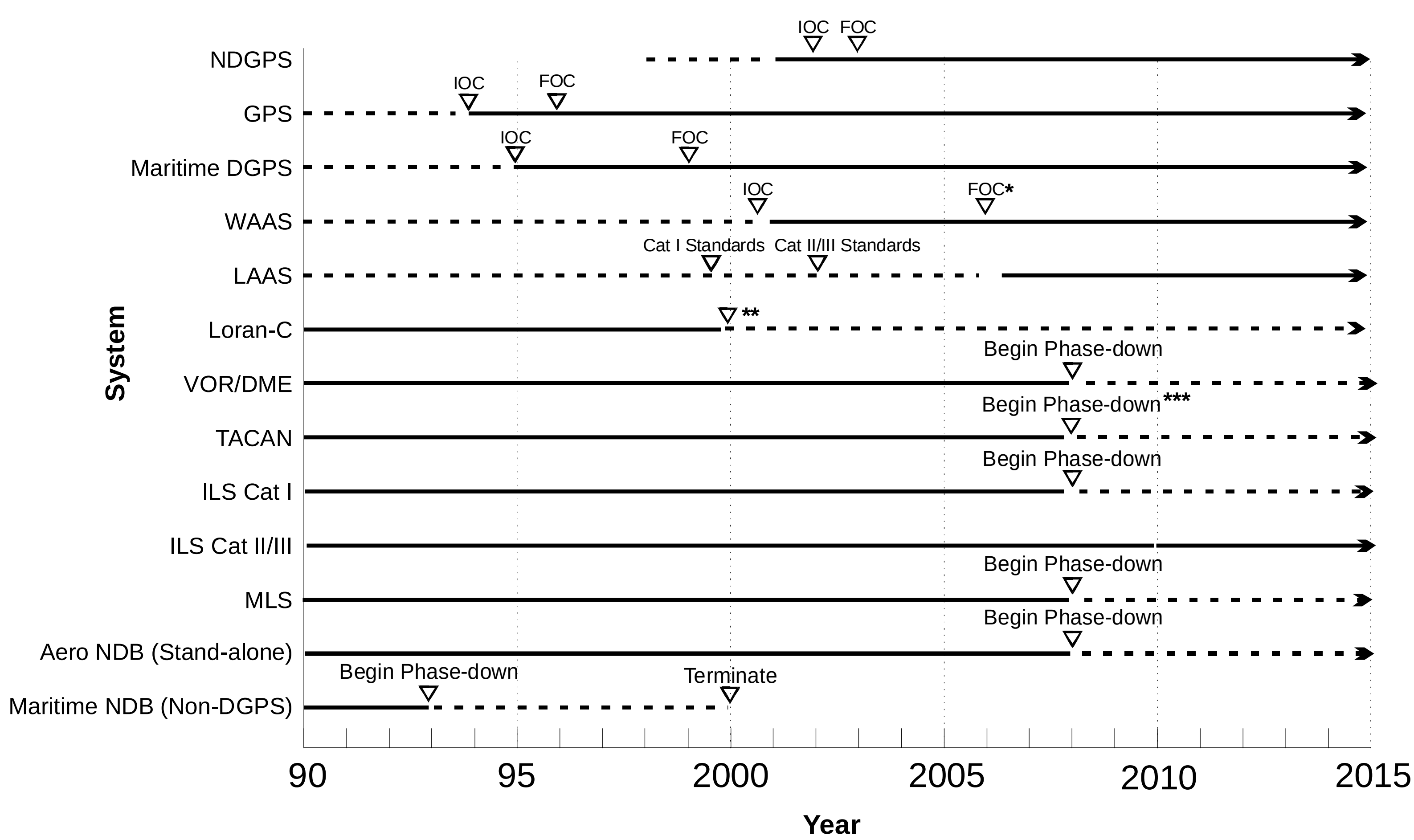
The GPS user community has grown exponentially in the past two years and that growth is expected to continue. Rapid growth has occurred in all modes of transportation. Non-transportation use is also growing at a rapid rate and includes users employed in surveying, farming, resource exploration, and law enforcement. The GPS signal, as defined in the Standard Positioning Service Signal Specification (Ref. 10), is designed to support civil GPS applications. The GPS PPS is restricted to U.S. Armed Forces, U.S. Federal agencies, and selected allied armed forces and governments. These restrictions are based on national security considerations.

B. Operating Plan

GPS will be the primary Federally provided radionavigation system for the foreseeable future. In certain regions of the world, GPS will be augmented to satisfy additional civil requirements for accuracy, coverage, availability, and integrity. The GPS constellation is configured and operated to provide the SPS signals to civil users in accordance with the GPS Standard Positioning Service Signal Specification (Ref. 10). The DOD will maintain a 24-satellite constellation. Replacement satellites will be launched on an expected failure strategy (a replacement satellite is launched when there are indications that a satellite should be replaced).

The DOD and DOT have agreed that representatives from the DOT will be located within the Master Control Station (MCS) and at the GPS Joint Program Office to participate in the day-to-day system operations, system development, and future requirements definitions.

Any planned disruption of the SPS in peacetime, other than planned GPS interference testing as described in Section 3.2.3, will be subject to a minimum of 48-hour advance notice provided by the DOD to the USCG Navigation Information Service (NIS) and the FAA Notice to Airman (NOTAM) system. A disruption is defined as periods in which the GPS is not capable of providing SPS as specified in the GPS Standard Positioning Service Signal Specification (Ref. 10). Unplanned system outages resulting from system malfunctions or unscheduled maintenance will be announced by the NIS and NOTAM systems (see Appendix C) as they become known.



* Projected date based upon achieved system performance.
** Loran-C will continue to operate in the short-term while the Administration continues to evaluate the long-term need for continuation of the system.
*** Unless determined to be necessary for long-term navigation services.
Note: Phase-down dates are targets and may be changed in subsequent editions of the FRP.

Figure 3-2. Radionavigation Systems Operating Plan

The FAA's GPS overlay initiative, which permits use of GPS to fly most existing NPA procedures, was of particular significance in achieving early operational benefits from GPS. The convenience of GPS for executing the thousands of existing VOR-and NDB-based NPAs was made immediately available to suitable equipped aircraft. In addition to "overlay" NPAs, the FAA moved aggressively to produce and publish GPS-based NPAs for runways without existing approaches, as well as improved approaches (lower minimums) for runways with existing NPAs. More than 2200 stand-alone GPS approaches have been published. Initial WAAS-based precision approach procedures are due to be published coincident with WAAS achieving its initial operational capability in the year 2000. A precision approach based on WAAS criteria will be designed for each runway end that is currently served by an existing conventional approach procedure. In addition, an NPA procedure will be developed with each precision approach procedure. The NPA will be usable by both WAAS and TSO-C129 receivers.

C. Spectrum

The L1 links of GPS and the Russian GLONASS system, the principal elements of the ICAO GNSS, operate in the 1559-1610 MHz aeronautical radionavigation/satellite navigation service frequency band. This is the sole band that is identified worldwide for the satellite-based aeronautical radionavigation requirements of civil aviation. The GPS L1 SPS ranging signal is a 2.046 MHz null-to-null bandwidth signal centered about 1575.42 MHz. The transmitted ranging signal that compromises the GPS-SPS is not limited to the null-to-null signal and extends through the band 1563.42 to 1587.42 MHz. WAAS, when it becomes operational, will utilize the same band and carrier frequency as GPS L1. Additionally, systems of pseudolites that may share the GPS L1 frequency or operate on an offset frequency have been proposed as an availability enhancement for LAAS.

The GPS L2 link shares the 1215-1260 MHz frequency band with the GLONASS L2 link and with the nationwide joint surveillance system radar network operated by DOD and FAA. The GPS L2 carrier frequency is 1227.60 MHz.

Additional signals are planned to enhance the ability of GPS to support civil users. These signals will assist in the mitigation of ionospheric-delay estimation errors and serve as backups for the GPS L1 link. A second non-safety-of-life civil signal will be added at the GPS L2 frequency (1227.60 MHz), and a third safety-of-life civil signal will be added at 1176.45 MHz.

3.2.2 GPS Modernization

The utility of GPS to support civil and military positioning and timing applications has grown tremendously during the 1990s. From hikers to automotive direction finding, aviation to spacecraft applications, GPS has become an integral part of our information infrastructure. Despite its revolutionary impact on navigation and timing applications, some improvements can make it significantly more useful and reduce the cost of augmentation systems and receiver equipment being designed to enhance and extend the current position and timing service provided by the GPS.

In 1997, the Air Force initiated a review of the capabilities of GPS. In an unprecedented teaming of the Departments of Defense, Transportation, Commerce, Interior, and Agriculture, plus NASA, both military and civil user requirements were collected. Current system shortcomings relative to those requirements were identified, and changes were recommended to improve the GPS service.

The first element of GPS Modernization was the decision to provide a civil signal at the L2 frequency. Civil users will be able to correct for ionospheric errors using a second frequency in addition to the current signal on L1. These corrections, when combined with setting Selective Availability (SA) to zero, will enable user equipment that meets benchmark standards to achieve horizontal accuracies in the 4 meter range. Vice President Gore announced the second civil signal decision on March 30, 1998. In addition, the Vice President announced that there would be a third civil signal for safety-of-life applications implemented on the Block II F satellites. In January 1999, it was announced that the second civil signal would be located at the L2 frequency (1227.60 MHz) and the third civil signal would be located at 1176.45 MHz, which is in an aeronautical radionavigation service protected band.

The GPS Modernization effort focuses on improving position and timing accuracy, availability, integrity monitoring support capability and enhancement to the control system to ensure a robust, highly dependable navigation and timing source for all users. As these system enhancements are introduced, users will be able to continue to use existing receivers, as signal backward compatibility is an absolute requirement for both the military and civil user community. Although current GPS users will be able to operate at the same, or better, levels of performance that they enjoy today, users will need to modify or procure new user equipment in order to take full advantage of any new signal structure enhancements.

GPS modernization will apply the principles of electronic and information warfare to ensure uninterrupted access to the PPS signal by U.S., Allied, and coalition forces. In addition, SA will be replaced with other means to deny hostile exploitation of the GPS service.

3.2.3 Interference Testing Coordination

In order to minimize service disruptions and prevent situations threatening safety or efficient use of GPS, any government agency or activity with a need to perform interference testing (i.e., transmit) in the GPS spectrum must coordinate with the FAA Spectrum Policy and Management Office. The FAA Spectrum Policy and Management Office acts as coordinator for any and all GPS interference testing. Due to guidance in the GPS Presidential Decision Directive (Ref. 2) that requires DOD to “develop measures to prevent hostile use of GPS and its augmentations to ensure that the United States retains a military advantage without unduly disrupting or degrading civilian uses,” the DOD has frequent need to perform interference testing. However, any and all other agencies with interference testing requirements must also coordinate through the FAA.

3.2.4 *Augmentations to GPS*

Unaugmented GPS will not meet all performance requirements for aviation, for the harbor entrance and approach phase of marine navigation, or for many land transportation applications. For example, an aircraft must have at least five satellites in view above a mask angle of 7.5 degrees in order to provide Receiver Autonomous Integrity Monitoring (RAIM). This condition is not always satisfied with the existing GPS constellation, resulting in so-called “RAIM holes” and limiting GPS to use as a supplemental navigation system. To meet the requirements for Fault Detection and Exclusion (FDE), at least six satellites with good geometry are necessary.

GPS may exhibit variances from a predicted grid established for navigation, charting, or derivation of guidance information. This variance may be caused by propagation anomalies, accidental perturbations of signal timing, and the implementation of SA.

Adverse effects of these variances may be substantially reduced, if not practically eliminated, by differential techniques. In such differential operation, a reference station is located at a fixed point (or points) within an area of interest. GPS signals are observed in real time and compared with signals expected to be observed at the fixed point. Differences between observed signals and predicted signals are transmitted to users as differential corrections to upgrade the precision and performance of the user’s receiver.

Non-navigation users of GPS who require few-centimeter accuracy or employ post processing to achieve few-decimeter to few-meter accuracy often employ augmentation somewhat differently from navigation users. For post processing applications using C/A code range, the actual observations from a reference station (rather than corrections) are provided to users. The users then compute corrections in their reduction software. Surveyors and other users who need sub-centimeter to few-centimeter accuracy in positioning from post-processing use two-frequency carrier phase observations from reference stations, rather than range data. The Continuously Operating Reference Stations (CORS) system is designed to meet the needs of both of the above types of these users.

3.2.4.1 *Maritime Differential GPS*

The USCG Maritime DGPS Service provides service for coastal coverage of the continental U.S., the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and portions of the Mississippi River Basin. Maritime DGPS uses fixed GPS reference stations that broadcast pseudo-range corrections using radionavigation radiobeacons. The Maritime DGPS Service provides radionavigation accuracy better than 10 meters (2 drms) for U.S. harbor entrance and approach areas.

A. User Community

Initially the U.S. Coast Guard identified four missions to be supported by the implementation of DGPS:

- Harbor Entrance and Approach Phase navigation

- Vessel Traffic Services (VTS)
- Aids to Navigation (ATON) positioning
- Exclusive Economic Zone (EEZ) surveying

The first is the only listed mission that requires navigation capability for both government and public users. The other three are government missions requiring a positioning service. In addition to the four Coast Guard identified missions, the USACE has partnered with the USCG to establish DGPS along many of the navigable inland rivers of the U.S. As a result, USACE surveying, positioning, dredging, revetment maintenance, and other navigation related activities are to be accomplished with improved levels of efficiency.

B. Operating Plan

The USCG declared Full Operational Capability (FOC) of the Maritime DGPS Service on March 15, 1999. Necessary steps to include DGPS as a system that meets the carriage requirements of the Navigation Safety Regulations (33 CFR 164), for vessels operating on the navigable waters of the U.S are being undertaken. In addition, the USCG on behalf of the U.S. Government intends to offer the Maritime DGPS Service to the IMO for recognition as a component of the worldwide radionavigation system

Recommended standards for maritime DGPS corrections have been developed by the Radio Technical Commission for Maritime Services (RTCM) Special Committee 104. The USCG is represented on this special committee and is using the SC-104 standard for its Maritime DGPS Service.

C. Spectrum

The Maritime DGPS Service operated by the USCG uses fixed GPS reference stations that broadcast GPS pseudorange corrections in the 285-325 kHz maritime radiobeacon band.

3.2.4.2 Nationwide Differential GPS (NDGPS)

A Nationwide DGPS (NDGPS) Service is being established to provide coverage for all areas of the U.S. not currently covered by the USCG Maritime DGPS Service.

This service is being established under the authority of P.L. 105-66 (Ref. 11) and is being implemented under a Memorandum of Agreement among the FRA, FHWA, USCG, OSTDOT, USAF, NOAA, and USACE.

A. User Community

Positive Train Control, Intelligent Transportation Systems, and precision agriculture are expected to receive benefits from the NDGPS Service.

B. Operating Plan

The NDGPS Service is expected to achieve IOC for land applications on December 31, 2002. The IOC phase is identified by the system's ability to provide accuracy, integrity, and single station broadcast coverage of the continental U.S.

The NDGPS Service will achieve FOC when it is capable of meeting the maritime broadcast standards of DGPS (Appendix C, section C.2.2.2) and provides dual coverage of the continental U.S. and selected portions of Hawaii and Alaska with single coverage elsewhere. FOC is expected December 31, 2003.

The service uses RTCM SC-104 standards.

C. Spectrum

NDGPS uses fixed GPS reference stations that broadcast pseudorange corrections in the 285-325 kHz maritime radiobeacon band.

3.2.4.3 Aeronautical GPS Wide Area Augmentation System (WAAS)

The WAAS is a safety-critical system designed primarily for aviation users consisting of the equipment and software that augments GPS. The WAAS provides a signal-in-space to WAAS users to support en route through precision approach navigation. The WAAS users include all certified aircraft using the WAAS for any approved phase of flight. The signal-in-space provides three services: (1) integrity data on GPS and Geostationary Earth Orbit (GEO) satellites, (2) differential corrections of GPS and GEO satellites to improve accuracy, and (3) a ranging capability to improve availability and continuity.

The GPS satellite data are received and processed at widely dispersed sites, referred to as Wide-area Reference Stations (WRS). These data are forwarded to processing sites, referred to as Wide-area Master Stations (WMS), which process the data to determine the integrity, differential corrections, residual errors, and ionospheric information for each monitored satellite and generate GEO satellite parameters. This information is sent to a Ground Earth Station (GES) and uplinked along with the GEO navigation message to the GEO satellites. The GEO satellites downlink these data on the GPS L1 frequency with a modulation similar to that used by GPS.

In addition to providing GPS integrity, the WAAS verifies its own integrity and takes any necessary action to ensure that the system meets performance requirements. The WAAS also has a system operations and maintenance function that provides information to FAA maintenance personnel.

A. User Community

Substantial benefits will accrue to both users and providers as the WAAS becomes operational and the aviation community transitions to WAAS avionics. Near-term user benefits will result from the use of a single navigation receiver that provides area navigation for all phases of flight and a significant increase in runways approved for precision approaches. When combined with necessary improvements in air traffic control automation, additional user benefits are expected to be derived from reduced IFR separations and more efficient routings. Near-term provider benefits will be derived from the decommissioning of redundant navigation systems and more cost-effective instrument approaches. The WAAS is also expected to be used extensively for numerous other civil applications where improved accuracy, integrity and availability are needed.

B. Operating Plan

The FAA is conducting a major system acquisition consisting of the WAAS operational system and functional verification system. The program strategy is to quickly field an initial WAAS that meets the basic requirements, and to enhance the system to meet the full WAAS requirements through a series of contract options.

WAAS is planned to achieve its initial operational capability by the end of 2000, and will provide en route through nonprecision approach service as well as a limited precision approach capability. After achieving initial operational capability, the WAAS will then be incrementally improved over the next six years to expand the area of coverage, increase the availability of precision approaches, increase signal redundancy, and reduce operational restrictions. The result of these incremental improvements will enable pilots equipped exclusively with WAAS avionics to execute all phases of flight in the NAS including Category I precision approach.

C. Spectrum

The WAAS will operate as an overlay on the GPS L1 link in the 1559-1610 MHz ARNS/RNSS frequency band. WAAS reference stations will also require codeless access to GPS L2 signals in the 1215-1260 MHz band to enhance system accuracy until such time as the second coded civil GPS signal is operational. The exact timeline and conditions will be specified in a jointly developed DOD/DOT transition plan.

3.2.4.4 Aeronautical GPS Local Area Augmentation System (LAAS)

A. User Community

The LAAS is a local GPS augmentation where the corrections to GPS (and WAAS) signals are broadcast to aircraft within line of sight of a ground reference station. LAAS is expected to support Category II/III applications. The system is also expected to provide Category I precision approaches at some high capacity airports which require increased availability and at locations where WAAS is unable to provide Category I precision approach services. LAAS may be used to support runway incursion warnings, high-speed turnoffs, missed approaches, departures, vertical takeoffs and surface operations.

B. Operating Plan

The FAA completed the development of Category I LAAS specifications in 1999 and plans to develop prototype systems to validate the ground station specification. There will be a subsequent effort to specify and validate CAT II/III LAAS performance. The FAA is also conducting research on providing airport surface traffic surveillance and guidance based on LAAS-augmented GPS.

C. Spectrum

The international community has evaluated spectral alternatives and has agreed with the FAA that the 108-117.975 MHz ARNS frequency band, currently populated by VORs and ILSs, is the candidate of choice for LAAS. Pseudolites sharing the GPS L1 frequency in a low duty cycle pulsed mode have been proposed as an availability enhancement for CAT II/III LAAS ground facilities.

3.2.4.5 The Continuously Operating Reference Station (CORS) System

The CORS system is a GPS augmentation being established by the NGS to support non-navigation, post-processing applications of GPS. The CORS system provides code range and carrier phase data from a nationwide network of GPS stations for access by the Internet. As of November 1998, data were being provided from about 144 stations.

A. User Community

The observational data provided by the CORS system are being used by government, academia, and industry groups to support most of the applications described in section 2.6. Currently, users are downloading about 1.6 gigabytes of data per day. The largest user groups, in terms of number of bytes downloaded, are academic and government research groups involved in geophysical studies of Earth movement. However, the largest numbers of users are private industry and Federal, state and local government users involved in surveying, mapping, charting, and GIS applications. These users require lesser quantities of data to support their applications.

National Geodetic Survey (NGS) has implemented CORS by making use of stations established by other groups, rather than by building an independent network of reference stations. In particular, use is being made of data from stations operated by components of DOT to support real-time navigation requirements. More than half of the stations now providing data for the CORS system are the stations of the USCG Maritime DGPS Service described in section 3.2.4.1. Stations of the WAAS network (described in section 3.2.4.3 above) will be CORS compatible, as well as the NDGPS stations being established by DOT to support land navigation. Other stations currently contributing data to the CORS system include stations operated by the National Oceanic and Atmospheric Administration (NOAA) and NASA in support of crustal motion activities, stations operated by state and local governments in support of surveying applications, and stations operated by NOAA’s Forecast Systems Laboratory in support of meteorological applications.

B. Operating Plan

The CORS system takes data to a Central Facility from the contributing stations using either the Internet or a telephone packet service (such as x.25). At the Central Data Facility, the data are converted to a common format, quality controlled, and place in files for access via Internet. The data are available via Internet for 50 days, after which they are archived on CD ROM. In addition to the data, the Central Data Facility provides software to support extraction, manipulation, and interpolation of the data. The precise positions of the CORS antennas are computed and monitored. In the future it is planned to compute and provide ancillary data, such as multipath models and tropospheric and ionospheric refraction models, to improve the accuracy of the CORS data.

C. Spectrum

Not applicable.

3.2.4.6 Vulnerability of GPS in the National Transportation Infrastructure

Appendix G of the Final Report of the President's Commission on Critical Infrastructure Protection was entitled, "Vulnerabilities of the NAVSTAR Global Positioning System and its Augmentations." This report concluded that GPS services and applications are susceptible to various types of interference, and that the effects of these vulnerabilities on civilian applications should be studied in detail. As a result of the report, Presidential Decision Directive 63 gave the Department of Transportation the following directive:

> The Department of Transportation, in consultation with the Department of Defense, shall undertake a thorough evaluation of the vulnerability of the national transportation infrastructure that relies on the Global Positioning System. This evaluation shall include sponsoring an independent, integrated assessment of risks to civilian users of GPS-based systems, with a view to basing decisions on the ultimate architecture of the modernized NAS on these evaluations.

This evaluation will assist the DOT in developing a plan for protecting the national transportation infrastructure. The focus of the study will be on the civilian user of the national transportation infrastructure, although the scope will include other civilian users and applications with appropriate authorities being notified of vulnerabilities as necessary.

DOT is expected to produce a report of current studies, a recommended plan of action for additional studies, a report of vulnerabilities to the national transportation infrastructure relying on GPS, and a recommendation as to priorities of risks and potential mitigation actions. The report is expected in 2000.

Presidential Decision Directive 63 also issued the following directive to the Federal Aviation Administration (FAA):

> The Federal Aviation Administration shall develop and implement a comprehensive National Airspace System Security Program to protect the modernized NAS from information-based and other disruptions and attacks.

Although not mentioned specifically, the security of GPS-reliant systems in the NAS is included. The FAA worked with the Air Transport Association of America (ATA) and the Aircraft Owners and Pilots Association (AOPA) to perform an independent GPS risk assessment. This study assesses the risks associated with the use of GPS and GPS enhanced by the Wide Area Augmentation System (WAAS) and the Local Area Augmentation System (LAAS) as the only navigation system required in aircraft operating within the NAS. The final report was delivered in January 1999. The main conclusions of the study are as follows:

- GPS with appropriate WAAS/LAAS configurations can satisfy navigation performance requirements as the only navigation system installed in the aircraft and the only navigation service provided by the U.S. Federal Government for aviation.
- Risks to GPS signal reception can be managed, but steps must be taken to minimize the effects of intentional interference.
- A definitive national GPS plan and management commitment is needed to establish system improvements with civil aviation users and to provide greater informational access to the civil aviation community.

The final report's findings are being assessed.

3.2.5 Loran-C

Loran-C was developed to provide military users with a radionavigation capability having much greater coverage and accuracy than its predecessor (Loran-A). It was subsequently selected as the Federally provided radionavigation system for civil marine use in the U.S. coastal areas. It is currently designated by the FAA as a supplemental system in the NAS. Loran-C can also be used for precise time interval and highly accurate frequency applications.

A. User Community

Although there is a steady trend towards the use of GPS, there remains a significant number of both maritime and aviation users of the Loran-C system. In addition, telecommunications and weather services use Loran-C as an economical timing device and weather services use it to determine upper air wind speed and direction by determining the change of position of radiosonde flights with time.

B. Operating Plan

While the Administration continues to evaluate the long-term need for continuation of the Loran-C radionavigation system, the Government will operate the Loran-C system in the short term. The U.S. Government will give users reasonable notice if it concludes that Loran-C is not needed or is not cost effective, so that users will have the opportunity to transition to alternative navigation aids. With this continued sustainment of the Loran-C service, users will be able to realize additional benefits. Improvement of GPS time synchronization of the Loran-C chains and the use of digital receivers may support improved accuracy and coverage of the service. Loran-C will continue to provide a supplemental means of navigation. Current Loran-C receivers do not support nonprecision instrument approach operations.

C. Spectrum

Loran-C operates in the 90-110 kHz frequency band.

3.2.6 VOR and VOR/DME

VOR was developed as a replacement for the Low-Frequency Radio Range to provide a bearing from an aircraft to the VOR transmitter. A collocated DME provides the distance from the aircraft to the DME transmitter. At most sites, the DME function is provided by the TACAN system that also provides azimuth guidance to military users. Such combined facilities are called VORTAC stations. Some VOR stations are used for broadcast of weather information.

A. User Community

VOR is the primary radionavigation aid in the National Airspace System and is the internationally designated standard short-distance radionavigation aid for air carrier and general aviation IFR operations. Because it forms the basis for defining the airways, its use is an integral part of the air traffic control procedures.

B. Operating Plan

The FAA operates 1012 VOR, VOR/DME, and VORTAC stations including 150 VOR-only stations. The number of stations is expected to remain stable until the VOR/DMEs begin to be decommissioned in 2008. The DOD also operates stations in the U.S. and overseas which are available to all users.

A small increase in the number of users equipped with VOR is expected over the next several years due to an increase in the aircraft population operating in the U.S. During this time, many users that are equipping their aircraft for VFR operation may choose to equip with GPS in preference to VOR. VOR/DME will still be required for IFR flight until the WAAS is approved for primary means navigation. It is then expected that VOR equipage will begin to rapidly decrease.

The current VOR/DME network will be maintained until 2008 to enable aircraft to become equipped with WAAS avionics and to allow the aviation community to become familiar with the system. Plans for expansion of the network are limited to site modernization or facility relocation, and the conversion of sub-standard VORs to a

Doppler VOR configuration. The phase-down of the VOR/DME and TACAN network is expected to begin in 2008.

From today’s full coverage network, the phase-down will transition through an interim network and then to a minimum operational network. This phased approach will allow for more efficient transition of airspace routings, encourage user equipage for area navigation, and maintain nonprecision approach alternatives. The minimum operational network will support IFR operations for the busiest airports in the NAS. A further reduction is then planned to the level of a basic backup network. Section 3.3 discusses the transition in more detail.

C. Spectrum

VOR operates in the 108-117.975 MHz frequency band. It shares the 108-111.975 MHz portion of that band with ILS. The FAA and the rest of the civil aviation community are investigating several potential aeronautical applications of the 108-117.975 MHz band for possible implementation after VOR and ILS have been partially or completely decommissioned. One of those future applications is LAAS. Another is the expansion of the present 117.975-137 MHz air/ground (A/G) communications band to support the transition to, and future growth of, the next-generation VHF A/G communications system for air traffic services.

DME operates in the 960-1027, 1033-1087, and 1093-1215 MHz sub-bands of the 960-1215 MHz ARNS band. It shares those sub-bands with TACAN. The frequency 1176.45 MHz has been selected as the third civil frequency (L5) for GPS. Location of GPS L5 in this protected ARNS band meets the needs of critical safety-of-life applications. The DOD’s Joint Tactical Information Distribution System/Multi-function Information Distribution System (JTIDS/MIDS) also operates in this band on a non-interference basis. The civil aviation community is investigating potential aeronautical applications of those sub-bands for implementation after DME and TACAN have been partially or completely decommissioned. These potential future applications include:

- Automatic Dependent Surveillance, Broadcast (ADS-B), a function in which aircraft transmit position and altitude data derived from onboard navigation systems.
- Traffic Information Services (TIS), in which processed surveillance data will be reported automatically from ground stations to aircraft in flight.
- A/G transfer of voice and data traffic for CNS services.
- Potential future CNS applications to support Free Flight.

The FAA is also considering the retention of a subset of the nationwide VOR/DME network. Continued use of some of the 108-117.975 MHz band would be needed to sustain the VOR elements of such a network. A substantial portion of the 960-1215 MHz ARNS band would be required to support its DME elements.

3.2.7 TACAN

TACAN is a UHF radionavigation system that is the military counterpart of VOR/DME. TACAN is the primary tactical air navigation system for the military services ashore and afloat. TACAN is often collocated with the civil VOR stations (VORTAC facilities) to permit military aircraft to operate in civil airspace.

A. User Community

There are presently approximately 14,500 aircraft that are equipped to determine bearing and distance to TACAN. These consist primarily of Navy, Air Force, and to a lesser extent, Army aircraft. Additionally, allied and third world military aircraft use TACAN extensively.

Because of propagation characteristics and radiated power, TACAN is limited to line-of-sight and is limited to approximately 180 miles at higher altitudes. As with VOR/DME, special consideration must be given to location of ground-based TACAN facilities, especially in areas where mountainous terrain is involved due to its line-of-sight coverage.

B. Operating Plan

DOD presently operates 173 TACANs and the FAA operates 609 TACANs for DOD. Present TACAN coverage ashore will be maintained until phased out in favor of GPS. However, the sea-based function of TACAN cannot be replaced by GPS unless combined with an appropriate data link function (ship to aircraft) with consideration for security, detection, classification, and exploitation threats. The potential to replace TACAN is being studied as a part of the Joint Precision Approach and Landing System (JPALS) program. The requirement for sea-based TACAN will continue until a suitable replacement is operational. Civil DME and the distance-measuring functions of TACAN will continue to be the same.

The DOD requirement for and use of land-based TACAN will continue until aircraft are properly integrated with GPS and when GPS is approved for all operations in national and international controlled airspace. Proper integration requires hardware and software modifications to GPS user equipment to meet navigation accuracy, integrity, availability, and continuity of service requirements. These modifications as well as development of operational procedures and navigation databases will require a transition period where TACAN must be retained. The target date to begin TACAN phase-down is 2008.

The FAA and DOD are conducting a NAS-wide prioritization review of FAA-operated TACAN facilities based on DOD mission requirements. The objective of the review is to identify and support critical facilities to ensure continued operation of these facilities to meet DOD needs. The prioritization assigns a class category to each facility.

- Class I - Critical, facilities essential for DOD operations. Class I facilities will continue to be maintained and operated with the support of a standby power source. Standby power may be provided by either an engine generator or a four-hour battery system.

- Class II - Non-Critical, facilities required, but not essential, for DOD operations. Class II facilities will continue to be maintained and operated but will not require a standby power source.

- Class III - Facility Not Required for DOD operations. Class III facilities will reduce service by eliminating TACAN azimuth service from operation.

C. Spectrum

TACAN operates in the 960-1027, 1033-1087, and 1093-1215 MHz sub-bands of the 960-1215 MHz ARNS frequency band. It shares those sub-bands with DME. The DOD's JTIDS/MIDS also operates in this band on a non-interference basis. The civil aviation community is investigating potential aeronautical applications of those sub-bands for implementation after DME and TACAN have been partially or completely decommissioned. Possible future applications are noted in Section 3.2.6.

3.2.8 ILS

ILS provides aircraft with precision vertical and lateral navigation (guidance) information during approach and landing. Associated marker beacons or DME equipment identify the final approach fix, the point where the final descent to the runway is initiated.

A. User Community

Federal regulations require U.S. part 121 air carrier aircraft to be equipped with ILS avionics. ILS also is extensively used by general aviation aircraft. A slight increase in the number of users equipped with ILS is expected over the next several years due to an increase in the aircraft population operating in the U.S. ILS equipage rates are then expected to rapidly decrease once the WAAS is approved for Category I approaches.

Because ILS is an ICAO standard landing system, it is extensively used by air carrier and general aviation aircraft of other countries.

B. Operating Plan

ILS is a standard civil precision approach system in the U.S. and abroad, and is protected by ICAO agreement to January 1, 2010. The FAA operates 1062 ILS systems in the NAS, of which 99 are Category II or Category III systems. In addition, the DOD operates 165 ILS facilities in the U.S.

For Category I precision approaches, ILS will remain in service together with WAAS to allow users an opportunity to equip with WAAS receivers and to become comfortable with its service. The phase-down of Category I ILS is expected to begin in 2008. For Category II/III precision approaches, new and upgrade requirements will continue to be met with ILS until LAAS systems are available. The FAA does not anticipate phasing out any Category II/III ILS systems prior to 2015.

As the GPS-based precision approach systems (WAAS/LAAS) are integrated into the NAS, and user equipage and acceptance grows, the ILS systems will be phased down. From today's full coverage network the phase-down will transition through an interim network and then to a minimum operational network. This phased approach will encourage user changeover to GPS-based approaches and maintain precision approach alternatives. The minimum operational network will support IFR operations for the busiest airports in the NAS. A further reduction is then planned to the level of a basic backup network. Section 3.3 discusses the transition in more detail.

As the ILS phase-down occurs, non-Federal sponsors may wish to continue their operation of their non-Federal ILS systems. Additionally, non-Federal sponsors may wish to take over operations and maintenance of some systems planned for decommissioning by the FAA.

C. Spectrum

ILS marker beacons operate in the 74.8-75.2 MHz frequency band. Since all ILS marker beacons operate on a single frequency (75 MHz), the aeronautical requirements for this band will remain unchanged until ILS has been completely phased out. No future aeronautical uses are envisioned for this band after ILS has been fully decommissioned.

ILS localizers share the 108-111.975 MHz portion of the 108-117.975 MHz ARNS band with VOR. As noted in Section 3.2.6, the FAA and the rest of the civil aviation community are investigating several potential aeronautical applications of this band for possible implementation after VOR and ILS have been partially or completely decommissioned. One of those future applications is LAAS. Another is the expansion of the present 117.925-137 MHz A/G communications band to support the transition to, and future growth of, the next-generation VHF A/G communications system for air traffic services. Substantial amounts of spectrum in the 108-111.975 MHz sub-band will continue to be needed to operate Category II and III localizers even after Category I ILS has been decommissioned.

ILS glide slope subsystems operate in the 328-335.4 MHz band. The FAA and the rest of the civil aviation community are investigating several potential aeronautical applications of this band for possible implementation after ILS has been partially or completely decommissioned. The inherent physical characteristics of this band, like those of the 108-111.975 MHz band, are quite favorable to long-range terrestrial line-of-sight A/G communications and data-link applications like LAAS, ADS-B and TIS. Consequently, this band is well suited to provide multiband diversity to such services or to serve as an overflow band for them if they cannot be accommodated entirely in other bands. Substantial amounts of spectrum in this band will continue to be needed to operate Category II and III ILS glide slope subsystems even after Category I ILS has been decommissioned.

3.2.9 MLS

MLS applications are limited to precision approach and landing. MLS is easier to cite than ILS and offers higher accuracy and greater flexibility, permitting precision approaches at more airports. MLS provides USAF tactical flexibility due to its ease in siting and adaptability to mobile operations. While there is limited user support for MLS in the U.S., it has continued to be a factor in other countries.

The USAF has implemented MLS capability on its fleet of C-130 aircraft for use with 37 Mobile MLS (MMLS) ground systems. The C-17 fleet is in the process of being equipped with a Multi-Mode Receiver (MMR) with enhanced ILS (radio interference protection), MLS, and GPS/JPALS/LAAS/WAAS growth capabilities. Additional fielding of MLS capability in the USAF will be driven by the extent of international civil and NATO Allied implementation. The U.S. Army and U.S. Navy currently have no plans to implement MLS.

A. User Community

FAA initiated a limited procurement of Category I MLS equipment in 1992. Twenty-nine Category I MLS systems have been installed. The FAA terminated the development of Category II and III MLS equipment based on favorable GPS test results.

B. Operating Plan

The U.S. does not anticipate additional MLS development. The phase-down of MLS is expected to begin in 2008.

C. Spectrum

MLS operates in the 5000-5250 MHz frequency band. The FAA and the rest of the civil aviation community are investigating potential aeronautical applications of this band for implementation after MLS has been partially or completely decommissioned. These include:

- An extension of the tuning range of the Terminal Doppler Weather Radar (TDWR) in order to relieve spectral congestion within its present limited operating band.
- Weather functions of the planned multipurpose primary terminal radar that will become operational around the year 2013.

3.2.10 Aeronautical Nondirectional Beacons (NDBs)

Aeronautical nondirectional beacons are used for transition from en route to precision terminal approach facilities and as nonprecision approach aids at many airports. In addition, some state and locally owned NDBs are used to provide weather information to pilots. However, GPS and the FAA’s automated weather observing system (AWOS) and automated surface observing system (ASOS) are providing the navigation and weather broadcast services currently met by NDBs.

A. User Community

All air carriers, most military, and many general aviation aircraft carry automatic direction finders (ADF). However, the importance of ADF is expected to decline with the increasing popularity of GPS.

Aircraft use radiobeacons as compass locators to aid in finding the initial approach point of an instrument landing system, for nonprecision approaches at low traffic airports without convenient VOR approaches, and for en route operations in some remote areas.

The large number of general aviation aircraft that are equipped with radio direction finders attests to the wide acceptance of radiobeacons by the user community. The primary reason for this acceptance is that adequate accuracy can be achieved with low-cost user equipment. However, now that GPS-based nonprecision approaches are available, transition from the NDB network can begin.

B. Operating Plan

The FAA operates over 700 NDBs. This number is expected to decline steadily over the next decade due to the increasing popularity of GPS. In addition, there are about 200 military NDBs and 800 non-Federally operated NDBs. During the next 10 years, FAA expenditures for beacons are planned to be limited to the replacement of deteriorated components, modernization of selected facilities, and an occasional establishment or relocation of an NDB used for ILS transition.

The FAA expects to decommission stand-alone NDBs starting in 2008. However, there may be cases where operation and maintenance of an NDB will be taken over by an individual operator or community desiring to delay its phaseout.

NDBs used as compass locators for ILS approaches, where no equivalent ground-based means for transition to the ILS course exists, will be maintained until the underlying ILS is itself phased out. A separate transition timeline will be developed for NDBs that define low frequency airways in Alaska.

C. Spectrum

Aeronautical NDBs operate in the 190-435 and 510-535 kHz frequency bands, portions of which it shares with maritime NDBs. Except in Alaskan airspace, no future civil aeronautical uses are envisioned for these bands after the aeronautical NBD system has been decommissioned throughout the rest of the NAS.

3.2.11 Maritime Radiobeacons

Maritime radiobeacons have remained as a backup to more sophisticated radionavigation systems and as a low-cost, medium accuracy system for vessels equipped with only minimal radionavigation equipment. Use and number of these beacons is dwindling very rapidly.

A. User Community

Radiobeacons are primarily used as homing devices for recreational boaters, but they also act as a backup for those users having more sophisticated radionavigation capability. As selected radiobeacons are modified to broadcast DGPS corrections, those radiobeacons will become a primary element in the harbor entrance and approach and coastal phases of navigation, used by all vessels, and required for certain classes of vessels. Due to single carrier operations, that eliminate the Morse tone identifier, maritime DGPS beacons do not conform to traditional radiobeacon standards.

Maritime radiobeacons have been an acceptable radionavigation tool for pleasure boaters using them for homing purposes, largely due to the adequate service with low-cost user equipment.

Marine radiobeacons provide a bearing accuracy relative to vehicle heading on the order of ± 3 to ± 10 degrees. This might be considered a systemic limitation but, in actual use, it is satisfactory for many navigation purposes. Radiobeacons are not satisfactory for marine navigation within restricted channels or harbors. They do not provide sufficient accuracy or coverage to be used as a primary aid to navigation for large vessels in U.S. coastal areas.

B. Operating Plan

Four maritime radiobeacons continue to be operated by the USCG. Many of the previously configured maritime radiobeacons have been modified to broadcast DGPS corrections for the Maritime DGPS Service; therefore, they no longer provide service as traditional homing devices.

With the availability of low-cost Loran-C and GPS receivers that provide far more flexible use to the boater, the use of radiobeacons has been continually declining. As the USCG conducts evaluation of the need for beacons, those with no identifiable user base will be discontinued. Maritime radiobeacons not modified to carry DGPS correction signals are expected to be phased out by the year 2000.

Although some aviation users have benefited from maritime radiobeacons, modulation of maritime radiobeacons with DGPS corrections will make these beacons unusable by digital aviation ADFs and may make their use by analog ADFs difficult.

3.3 Phase-Down of Ground-Based Aeronautical Navaids

3.3.1 Transition to Satellite-Based Navigation (Satnav)

The FAA is planning to transition into providing Satnav services based primarily on GPS augmented by the Wide Area Augmentation System (WAAS) and the Local Area Augmentation System (LAAS). As a result of this transition, the number of Federally provided ground-based navigation facilities will be reduced to coincide with a reduction in the need for ground-based navigation services. Transition to a totally new system represents a substantial undertaking—one that will require a major investment of resources by both the FAA and the aircraft owners and operators. Three essential prerequisites must be met for such a massive transition to take place:

- *System Performance:* Through analyses, flight tests, and substantial operational experience, aircraft operators and the FAA must be convinced that the new system meets their requirements for accuracy, integrity, availability, and continuity of service.
- *Operational Benefit:* The aircraft operator must perceive sufficient operational benefit to warrant an investment in the new technology.
- *Transition Period:* The aircraft operators must have sufficient time to recoup their investment in conventional avionics. Although many avionics systems have been used for 15 to 20 years or more, a reasonable compromise must be reached between the FAA’s desire for a rapid transition (to avoid further investment in ground-based Navaids) and the aircraft operators’ desire to use current avionics as long as possible.

The transition period begins when the capability is established for a pilot to perform navigation procedures throughout the NAS using Satnav as the only means of radionavigation aboard an aircraft. This will occur when WAAS achieves its full operational capability and procedures to use the new capability have been published (i.e., precision and nonprecision Satnav instrument approach procedures). Prior to this, even new aircraft must be equipped with avionics for the conventional ground-based Navaids. The transition period ends when the conventional Navaids have been reduced to the extent that they are unnecessary for routine NAS operations.

The reduction in Federally provided Navaid services can be performed in several distinct steps. This approach would allow the FAA to begin the phaseout gradually, providing users sufficient time to equip with Satnav avionics. A more abrupt transition would be too disruptive to NAS operations and would place too great a burden on the users. The proposed phase-down strategy is depicted in Figure 3-3. The FAA is evaluating alternatives for the future navigation architecture and will update the transition plans as Satnav program milestones are achieved; as the actual performance of Satnav systems is documented; and as users equip with Satnav avionics.

The proposed transition strategy involves a two-step phase-down from the current full coverage network of Navaids to a reduced network that supports a substantial number of currently certified airways, jet routes, and instrument approach procedures. This network, termed the Minimum Operational Network, is a scaled-down version of the current infrastructure of VORs, ILSs, MLSs, and NDBs. The phase-down strategy would provide the FAA and the airspace users with a safe recovery and sustained operations capability in the event of a disruption in Satnav service. A follow-on step to a basic backup network is also depicted in Figure 3-3.

The Navaid phase-down can be initiated after the following conditions have been met:

- WAAS has achieved FOC and has been approved as an only means of radionavigation for a given flight operation (at FOC, WAAS will comply with its end-state requirements, providing a level of availability sufficient to replace existing VOR/DME and NDB facilities, and many Category I ILS facilities).
- Procedures to use the new WAAS capability have been published.
- A majority of the airspace users have equipped with appropriate WAAS avionics.

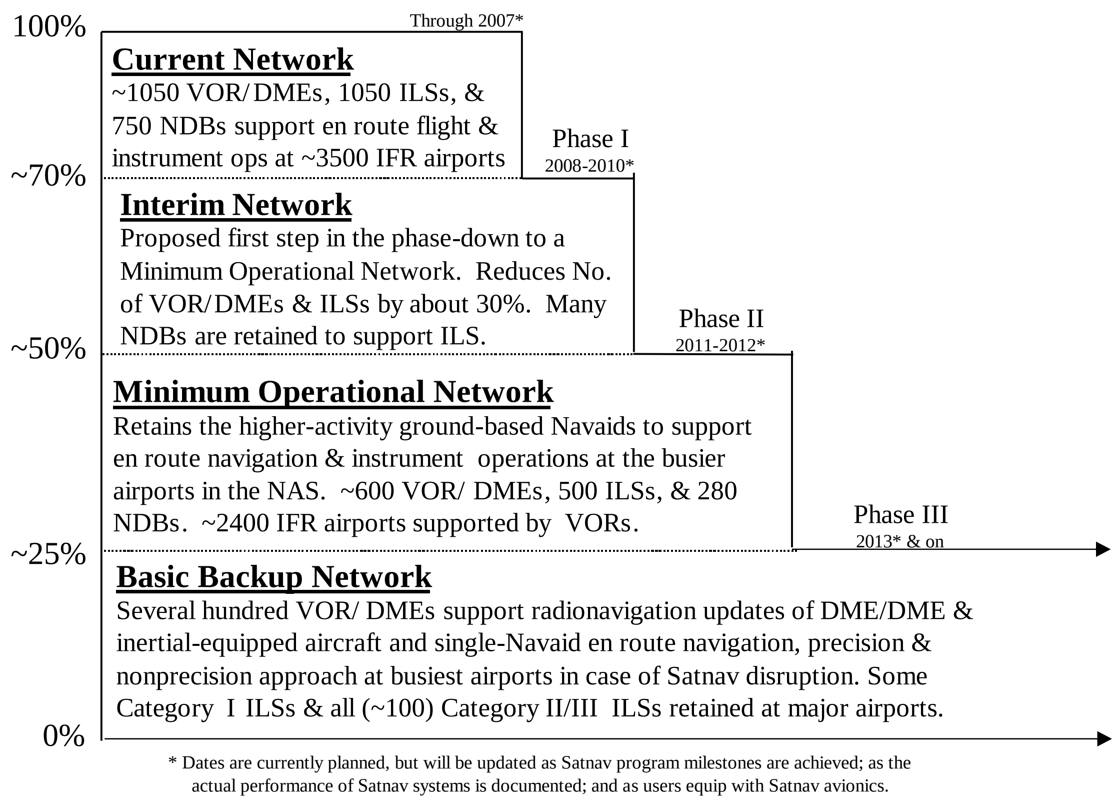


Figure 3-3. Proposed Civil Aeronautical Navaid Phase-Down Steps

The phase-down is planned to begin in 2008 based on projected Satnav program milestones and anticipated user equipage rates.

The specific Navaids that would no longer qualify for Federal support, at each step of the phase-down, would be determined based on specific criteria, currently under development. Navaids supporting en route procedures would be decommissioned. Navaids supporting terminal procedures could be decommissioned or transitioned to a non-Federal sponsor.

The discontinuance criteria would be published as early as possible and well ahead of the phase-down. A site-specific list of Navaids fitting the discontinuance criteria would be published later—perhaps at the time of WAAS FOC. The advanced site-specific notice would afford users the opportunity to plan their transition to Satnav based upon the operational schedule for the specific Navaids they use most often.

- *Phase I* – Many currently under-utilized VORs and ILSs would be discontinued at the first step of the phase-down. Preliminary analysis indicates that approximately 350 VORs and 300 ILSs would no longer qualify for Federal support at this first step. (The population of NDBs would remain essentially intact to support ILS approaches.) Although this represents an approximate 30 percent reduction in the number of Navaids, it would be expected to cause a relatively minor impact on the NAS.
- *Phase II* – The second step, planned to occur in 2011, would further reduce the population of ground-based Navaids to the level of the proposed Minimum Operational Network. The Phase II Navaids are intended to support continued operation in the NAS by those aircraft not yet equipped with Satnav avionics, albeit at a reduced level of efficiency. Although this represents an approximate 50 percent reduction in the number of Federally supported Navaids, the remaining network would continue to support a robust set of IFR operations.
- *Phase III* – Previous plans were to complete the transition to Satnav with the phase-out of all the remaining ground-based Navaids. However, a more conservative approach now planned by the FAA is to step-down to a subset of ground-based Navaids that would continue to support Satnav operations beyond 2012. A candidate "Basic Backup Network" composed of several hundred conventional VOR/DME Navaids would allow aircraft equipped with DME/DME avionics to continue en route navigation using dual-DME position updates. It would also provide a nonprecision instrument approach capability at selected airports. A limited number of Category I ILSs, and virtually all existing Category II/III ILSs, would also be retained to support prevision instrument approaches at major airports.

3.3.2 Satnav as an Only Means of Radionavigation

The FAA's goal is to approve Satnav as the only radionavigation system required to be installed in an aircraft to support operations anywhere in the NAS. The Air Transport Association of America and the Aircraft Owners and Pilots Association conducted a risk assessment of using Satnav technology as an only means of radionavigation in the NAS. The study was conducted by the Johns Hopkins University Applied Physics Lab under the oversight of the RTCA Free Flight Steering Committee and with FAA funding. The final report concluded that GPS with appropriate WAAS/LAAS configurations can satisfy the required navigation performance as the only navigation system installed in the aircraft and the only navigation service provided by the FAA (see Section 3.2.4.6). However, from a service provider perspective, the FAA plans to continue operating a subset of conventional ground-based Navaids for those users choosing to remain equipped with conventional avionics.

There is concern about potential disruptions to Satnav service, primarily due to the relatively weak signals received from the GPS satellites. As one example, the President's Commission on Critical Infrastructure Protection highlighted GPS vulnerability and questioned its use as the only means of radionavigation in the NAS. The predominant concerns relate to a potential loss of service from intentional jamming, unintentional radio frequency interference, or ionospheric scintillation during severe solar storms. Intentional jamming is the most difficult threat to overcome.

- The effects of jamming and unintentional interference are primarily to increase the workload of both the users and the air traffic controllers. Pilots and controllers will work together to assure safety, but a loss of navigation and landing capabilities increases the demand for services. Operational restrictions would likely be necessary in the event of an outage to balance demand and assure safety.

- Solar effects are expected to have only minimal impact on CONUS airspace. The greatest impact is expected in the polar regions and near the equator. Most aircraft operating on polar routes are equipped with inertial systems and can operate for many hours between radionavigation updates before violating separation requirements. Some care will be needed in high-latitude and equatorial zone Satnav-based instrument approaches at night.

A loss of GPS service in the absence of any other means of radionavigation would have varying negative effects on air traffic operations. These effects range from nuisance events requiring standard restoration of capabilities to an inability to provide service within one or more sectors of airspace for a significant period of time.

3.3.3 Mitigation of Potential Satnav Disruptions

Several solutions have been identified to help mitigate the effects of a Satnav service disruption, but each has its limitations.

- The L5 civil frequency planned for GPS will help alleviate the impacts of both solar activity and unintentional interference, but it may be 2013 or later before a full constellation of dual-frequency satellites is available. The cost implications of the L5 civil frequency are not yet defined.

- Modern transport-category turbojet aircraft, when engaged in relatively stable en route flight, may be able to continue navigating safely an hour or more after losing radionavigation position updating. In some cases, this capability may prove adequate to depart an area with localized jamming or proceed under visual flight rules during good visibility and high ceilings. However, inertial performance without radionavigation updates degrades substantially faster on a maneuvering aircraft, and the viability of continued terminal-area navigation is unclear. There is no assurance of compliance with airspace requirements after executing a procedural turn or entering a holding pattern, even in en route airspace.

- Integrated GPS/inertial avionics having significant anti-jam capability could greatly reduce the area affected by a GPS jammer or by unintentional interference. Industry research is proceeding to develop this technology, with an expectation that it might be marketed to the general aviation community. However, significant certification challenges will be encountered, and some users may still find this technology to be unaffordable.

- A basic backup network composed of several hundred conventional VOR/DME Navaids would allow aircraft equipped with DME/DME avionics to continue en route navigation using dual-DME position updates. It would also provide a nonprecision instrument approach capability at selected airports. However, low-altitude users may need to be vectored by air traffic controllers into an area with VOR coverage or to an area in visual meteorological conditions. Additional Navaids (where required) may also be needed for missed approaches and departures where terrain or obstruction clearances must be maintained—particularly in non-radar environments.
- Users may have an option to equip with IFR-certified Loran-C avionics, pending the improvements needed to achieve a nonprecision instrument approach capability with Loran. A combined Loran/Satnav receiver could provide navigation and nonprecision instrument approach service throughout any disruption to Satnav service.
- If a majority of operations are conducted by aircraft equipped with an additional navigation capability (e.g., inertial or Loran), then the balance should be able to be managed with air traffic control vectors based on an independent (radar) surveillance system. Additional research may be necessary to validate this concept in terms of the impact to air traffic controller workload and the sensitivity to the proportion of backup-equipped aircraft.
- An ILS (or MLS) may need to be retained at major airports to provide a backup precision approach capability, and where necessary to support international compatibility. ILSs may also be needed at a few remote airports where the distance to the closest major (ILS-equipped) airports is excessive.

3.3.4 Long-Term Transition Plans

The pace and extent of the transition to Satnav will depend upon a number of factors related to system performance and user acceptance. The FAA plans to reduce ground-based Navaids subject to these factors.

A decision to retain a selected subset of ground-based Navaids to support satellite navigation does not need to be made until well after experience is gained with Satnav technology. Some site-specific Navaids will face the end of their serviceable life before 2010. The need to replace selected Navaids will require investment analysis and investment decisions on what specific Navaids to retain.

The FAA's plans for the transition to Satnav and for the phase-down of ground-based Navaids will be periodically reevaluated. These plans need to remain flexible, and may need to be adjusted as Satnav program milestones are achieved, as the actual performance of Satnav systems is demonstrated, and as users equip with Satnav avionics. The transition plans will continue to be closely coordinated with airspace users and with the FAA's air traffic control community.

3.4 Interoperability of Radionavigation Systems

3.4.1 Overview

Radionavigation systems are sometimes used in combination with each other or with other systems. These combined systems are often implemented so that a major attribute of one system will offset a weakness of another. For example, a system having high accuracy and a low fix rate might be combined with a system with a lower accuracy and higher fix rate. The combined system would demonstrate characteristics of a system with both high accuracy and a high fix rate.

3.4.2 GPS/GLONASS

Manufacturers of navigation and positioning equipment are beginning to develop and manufacture combined GPS/GLONASS receivers to take advantage of these benefits. Some receivers are on the market with others in the planning stage. The RTCA SC 159 is developing a Minimum Operation Performance Standard (MOPS) for a combined GPS and GLONASS system. The Airlines Electronic Engineering Committee (AEEC) is developing specifications for a multimode receiver that includes GLONASS. The satellite communications MOPS and SARPs provide for both GPS and GLONASS protection.

A combination of GPS and GLONASS has several potential benefits over either system alone. Combining the capability in one receiver to navigate using satellites from the GPS and GLONASS constellations results in a receiver with improved navigation and positioning availability worldwide, improved polar coverage, improved resistance to interference and jamming and improved RAIM and FDE. The FAA has entered into a bilateral agreement with the Russian Federation to investigate a combined GPS/GLONASS avionics receiver that could take advantage of the two constellations.